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Characterization of Engine Mount Elastomers

J.P. Szabo

Defence R&D Canada – Atlantic

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14. ABSTRACT

As part of a project to develop methods for modelling the performance of engine mounts several oil resistant alternative materials were prepared, and compared to conventional materials from mounts that are currently in service on the Canadian Patrol Frigate (CPF). This report describes the preparation and characterization of these elastomers, ncluding two that were prepared at Platform Sciences Laboratory (PSL) in Melbourne, Australia under the Canada/ Australia MOU on Defence Science and Technology, Subsidiary Arrangement No. 16, Vibration Isolation Materials For Naval Vessels. The dynamic mechanical properties of the elastomers were determined as a function of frequency and strain amplitude. At strain amplitudes > 400 μm, the storage moduli were generally independent of amplitude, once the moduli were corrected for changes in sample cross-sectional area resulting from tensile pre-strain. The storage moduli at 1 Hz, 20oC were in the range 3-7 MPa. The loss factors of the elastomers at 1 Hz, 20oC varied considerably, from 0.02 for natural rubber to 0.27 for ethylene acrylic elastomer. Swelling experiments of the elastomers in diesel fuel and lubricating oil demonstrated that the two elastomers prepared by PSL were in fact quite resistant to hydrocarbons. However, the hydrocarbon compatibility data for nitrile rubber/ plasticized PVC blend suggest that some plasticizer leaching occurred on exposure to lubricating oil. The frequency-dependent dynamic mechanical properties of the elastomers presented in this report were used in VAST Finite Element models of engine mounts, and in VVES models of engine vibration isolation systems. Hydrocarbon compatibility experiments suggest that ethylene acrylic elastomer would be a suitable replacement for natural rubber and neoprene rubber in engine mounts where exposure to hydrocarbon fluids is a concern.

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Abstract

As part of a project to develop methods for modelling the performance of engine mounts, several oil resistant alternative materials were prepared, and compared to conventional materials from mounts that are currently in service on the Canadian Patrol Frigate (CPF). This report describes the preparation and characterization of these elastomers, including two that were prepared at Platform Sciences Laboratory (PSL) in Melbourne, Australia under the Canada/ Australia MOU on Defence Science and Technology, Subsidiary Arrangement No. 16, Vibration Isolation Materials For Naval Vessels.

The dynamic mechanical properties of the elastomers were determined as a function of frequency and strain amplitude. At strain amplitudes > 400 μm, the storage moduli were generally independent of amplitude, once the moduli were corrected for changes in sample cross-sectional area resulting from tensile pre-strain. The storage moduli at 1 Hz, 20°C were in the range 3-7 MPa. The loss factors of the elastomers at 1 Hz, 20°C varied considerably, from 0.02 for natural rubber to 0.27 for ethylene acrylic elastomer. Swelling experiments of the elastomers in diesel fuel and lubricating oil demonstrated that the two elastomers prepared by PSL were in fact quite resistant to hydrocarbons. However, the hydrocarbon compatibility data for nitrile rubber/ plasticized PVC blend suggest that some plasticizer leaching occurred on exposure to lubricating oil.

The frequency-dependent dynamic mechanical properties of the elastomers presented in this report were used in VAST Finite Element models of engine mounts, and in VVES models of engine vibration isolation systems. Hydrocarbon compatibility experiments suggest that ethylene acrylic elastomer would be a suitable replacement for natural rubber and neoprene rubber in engine mounts where exposure to hydrocarbon fluids is a concern.

Résumé

Dans le cadre d'un projet visant à élaborer des méthodes de modélisation de la performance des bâtis de moteur, plusieurs matériaux de remplacement résistants à l'huile ont été préparés et leurs propriétés et leur performance ont été comparées à celles des matériaux classiques qui sont actuellement utilisés sur les navires du type Frégate canadienne de patrouille (FCP). Le présent rapport contient la description des méthodes de préparation et de caractérisation des matériaux de remplacement en question, soit des élastomères, y compris deux matériaux qui ont été préparés au Platform Sciences Laboratory (PSL) de Melbourne (Australie), en vertu du protocole d'entente entre le Canada et l'Australie, portant sur les sciences et technologies appliquées à la défense (arrangement subsidiaire numéro 16, sur les matériaux antivibrations pour navires militaires).

On a déterminé les propriétés mécaniques dynamiques des élastomères en fonction de la fréquence et de l'amplitude de la déformation. Pour des valeurs d'amplitude de la déformation supérieures à 400 μm, le module de conservation est généralement indépendant de l'amplitude, une fois qu'un facteur de correction a été appliqué au module, afin de tenir compte des variations de la superficie de la section transversale qui sont attribuables à la traction subie avant la déformation. Les valeurs du module de conservation, à une fréquence

de 1 Hz et à 20 °C, se situent dans l'intervalle de 3 à 7 MPa. Les valeurs du facteur de perte des élastomères, à une fréquence de 1 Hz et à 20 °C, varient grandement, car elles se situent entre 0,02 pour le caoutchouc naturel et 0,27, dans le cas de l'élastomère à base de copolymère d'éthylène/acide acrylique. Les résultats des essais de gonflement des élastomères dans du carburant diesel et de l'huile lubrifiante indiquent que les deux élastomères préparés au PSL résistent assez bien aux hydrocarbures. Toutefois, dans le cas d'un mélange de caoutchouc nitrile et de poly(chlorure de vinyle) [PVC] plastifié, les données sur la compatibilité des produits en présence d'hydrocarbures semblent indiquer qu'une certaine lixiviation du plastifiant se produit lors de l'exposition à de l'huile lubrifiante.

Les données sur la relation entre la fréquence et les propriétés mécaniques dynamiques des élastomères faisant l'objet du présent rapport ont été utilisées dans l'élaboration de modèles à éléments finis du type VAST (vibration et résistance) de bâtis de moteur, ainsi que celle des modèles VVES (vibration de structures vibro-élastiques et élastiques) de systèmes antivibrations pour moteurs. Les résultats des essais de compatibilité des produits en présence d'hydrocarbures semblent indiquer que l'élastomère à base de copolymère d'éthylène/acide acrylique constitue un produit de remplacement acceptable du caoutchouc naturel et du caoutchouc néoprène, dans les bâtis de moteur où l'exposition aux hydrocarbures liquides peut constituer un problème.

Executive summary

Background

Engine mounts on marine vessels are often subjected to an environment where hydrocarbons from lubricants or fuel come in contact with the elastomeric component of the mount. When natural rubber is used as the elastomer, hydrocarbons can cause the rubber to swell, altering its mechanical properties in an unpredictable and often undesirable manner.

As part of a project to develop methods for modelling the performance of engine mounts, several oil resistant alternative materials were prepared, and compared to conventional materials from mounts that are currently in service on the Canadian Patrol Frigate (CPF). This report describes the preparation and characterization of these elastomers, including two that were prepared at Platform Sciences Laboratory (PSL) in Melbourne, Australia under the Canada/ Australia MOU on Defence Science and Technology, Subsidiary Arrangement No. 16, Vibration Isolation Materials For Naval Vessels.

Principal Results

The dynamic mechanical properties of the elastomers were determined as a function of frequency and strain amplitude. At strain amplitudes > 400 μm, the storage moduli were generally independent of amplitude, once the moduli were corrected for changes in sample cross-sectional area resulting from tensile pre-strain. The room temperature storage moduli were in the range 3-7 MPa. The loss factors of the elastomers at 1 Hz, 20^{o}C varied considerably, from 0.02 for natural rubber to 0.27 for ethylene acrylic elastomer. Swelling experiments of the elastomers in diesel fuel and lubricating oil demonstrated that the two elastomers prepared by PSL were in fact quite resistant to hydrocarbons. However, the hydrocarbon compatibility data for nitrile rubber/ plasticized PVC blend suggest that some plasticizer leaching occurred on exposure to lubricating oil.

Significance of Results

The frequency-dependent dynamic mechanical properties of the elastomers presented in this report were used in VAST Finite Element models of engine mounts, and in VVES models of engine vibration isolation systems. Hydrocarbon compatibility experiments suggest that ethylene acrylic elastomer would be a suitable replacement for natural rubber and neoprene rubber in engine mounts where exposure to hydrocarbon fluids is a concern.

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Sommaire

Contexte

Les bâtis de moteur de navires sont souvent soumis à des conditions ambiantes dans lesquelles des hydrocarbures provenant d'un lubrifiant ou d'un carburant entrent en contact avec les constituants élastomères du bâti. Lorsque l'élastomère est du caoutchouc naturel, les hydrocarbures peuvent entraîner son gonflement et altérer ses propriétés mécaniques de manière imprévisible et, dans de nombreux cas, indésirable.

Dans le cadre d'un projet visant à élaborer des méthodes de modélisation de la performance des bâtis de moteurs, plusieurs matériaux de remplacement résistants à l'huile ont été préparés et leurs propriétés et leur performance ont été comparées à celles des matériaux classiques qui sont actuellement utilisés sur les navires du type Frégate canadienne de patrouille (FCP). Le présent rapport contient la description des méthodes de préparation et de caractérisation des matériaux de remplacement en question, soit des élastomères, y compris deux matériaux qui ont été préparés au Platform Sciences Laboratory (PSL) de Melbourne (Australie), en vertu du protocole d'entente entre le Canada et l'Australie, portant sur les sciences et technologies appliquées à la défense (arrangement subsidiaire numéro 16, sur les matériaux antivibrations pour navires militaires).

Principaux résultats

On a déterminé les propriétés mécaniques dynamiques des élastomères en fonction de la fréquence et de l'amplitude de la déformation. Pour des valeurs d'amplitude de la déformation supérieures à 400 μm, le module de conservation est généralement indépendant de l'amplitude, une fois qu'un facteur de correction a été appliqué au module, afin de tenir compte des variations de la superficie de la section transversale qui sont attribuables à la traction subie avant la déformation. Les valeurs du module de conservation, à la température ambiante, se situent dans l'intervalle de 3 à 7 MPa. Les valeurs du facteur de perte des élastomères, à une fréquence de 1 Hz et à 20 °C, varient grandement, car elles se situent entre 0,02 pour le caoutchouc naturel et 0,27 dans le cas de l'élastomère à base de copolymère d'éthylène/acide acrylique. Les résultats des essais de gonflement des élastomères dans du carburant diesel et de l'huile lubrifiante indiquent que les deux élastomères préparés au PSL résistent assez bien aux hydrocarbures. Toutefois, dans le cas d'un mélange de caoutchouc nitrile et de poly(chlorure de vinyle) [PVC] plastifié, les données sur la compatibilité des produits en présence d'hydrocarbures semblent indiquer qu'une certaine lixiviation du plastifiant se produit lors de l'exposition à de l'huile lubrifiante.

Importance des résultats

Les données sur la relation entre la fréquence et les propriétés mécaniques dynamiques des élastomères faisant l'objet du présent rapport ont été utilisées dans l'élaboration de modèles à éléments finis du type VAST (vibration et résistance) de bâtis moteurs, ainsi que celle de modèles VVES (vibration de structures vibro-élastiques et élastiques) de systèmes antivibrations pour moteurs. Les résultats des essais de compatibilité des produits en présence

d'hydrocarbures semblent indiquer que l'élastomère à base de copolymère d'éthylène/acide acrylique constitue un produit de remplacement acceptable du caoutchouc naturel et du caoutchouc néoprène, dans les bâtis moteurs où l'exposition aux hydrocarbures liquides peut constituer un problème.

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Acknowledgements

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1. Introduction

Engine mounts on marine vessels are often subjected to an environment where hydrocarbons from lubricants or fuel come in contact with the elastomeric component of the mount. When natural rubber is used as the elastomer, hydrocarbons can cause the rubber to swell, altering its mechanical properties in an unpredictable and often undesirable manner.

As part of a project to develop methods for modelling the performance of engine mounts [1], several oil resistant alternative materials were prepared, and compared to conventional materials from mounts that are currently in service on the Canadian Patrol Frigate (CPF). This report describes the preparation and characterization of several elastomers, including two that were prepared at Platform Sciences Laboratory (PSL) in Melbourne, Australia under the Canada/ Australia MOU on Defence Science and Technology, Subsidiary Arrangement No. 16, Vibration Isolation Materials For Naval Vessels. The frequency-dependent dynamic mechanical properties of the elastomers presented in this report were used in VAST Finite Element models of engine mounts, in VVES models of engine vibration isolation systems, and in modal analysis of small scale experimental isolation systems. The results of these modelling studies are presented elsewhere [1, 2, 3, 4, 5, 6, 7, 8].

2. Elastomer Descriptions

The elastomer descriptions are given below and summarized in Table 1.

2.1 Elastomer A

Elastomer A is a carbon black filled natural rubber prepared at PSL. It was prepared in 2.7 mm sheets for material characterization, and in blocks approximately 25 mm x 50 mm x 24 mm in size for reduced scale vibration isolation experiments.

2.2 Elastomer B

Elastomer B is a blend of carbon black filled nitrile rubber (NBR), polyvinylchloride (PVC), and diisooctyl phthalate (DIOP) that was formulated at PSL (as AMRL 2046). The ratios of components in this blend was 50 NBR/ 25 PVC/ 25 DIOP. This material was prepared at PSL for study as an alternative oil resistant elastomer, in sheets of thickness 1.9 mm.

2.3 Elastomer C

Elastomer C is an ethylene acrylic elastomer (trade name Vamac) that was prepared at PSL (as AMRL 2047). This material was prepared for study as an alternative oil resistant elastomer, in sheets of thickness 1.8 mm

2.4 Elastomer D

The CPF Propulsion Diesel Engine (PDE) is an SEMT-Pielstick 20PA6 V280 model. It is supported by an isolation system that consists of engine mounts, a raft, and raft mounts. Elastomer D is carbon black filled natural rubber used in the fabrication of *engine mounts* on the PDE. The engine mounts are Metalastik® type D series, Product No. 17-1601-03, available from Trelleborg Industrial AVS Limited (http://www.trelleborg.com/). Annex A contains a product sheet description of this mount.

2.5 Elastomer E

Elastomer E is carbon black filled natural rubber used in the fabrication of *raft mounts* on the CPF Propulsion Diesel Engine. The raft mounts are Metalastik® type Equi-Frequency mountings large series, Product No. 17-1472-00, available from Trelleborg Industrial AVS Limited (http://www.trelleborg.com/). Annex A contains a product sheet description of this mount.

2.6 Elastomer F

Naval Engineering Test Establishment (NETE) has an MWM diesel engine that is used as an engineering test bed. This engine is supported by 6 Lord Corporation Flexbolt Sandwich Mounts, Part number J-5130-1, available from RPM Mechanical Inc (www.rpmmech.com). Elastomer F is a carbon black filled neoprene rubber used in the manufacture of the Lord mounts. Annex A contains a product sheet description of this mount.

3. Methodology

3.1 Sample Preparation

Elastomers A, B, and C were prepared using rubber compounding equipment at PSL in Melbourne, Australia, and sent to DRDC Atlantic for characterization. Samples for DMTA and immersion tests were cut using a scalpel.

Elastomers E, D, and F were components of engine mounts, and were bonded to metallic components, as shown in Figures 1-3. Elastomer samples were prepared by first cutting mounts into small pieces using a saw, then using waterjet cutting to obtain samples of rectangular geometry. Waterjet cutting was carried out at RCI Waterjet Cutting Services Inc., Mississauga, Ontario.

3.2 Immersion Tests

In order to study the hydrocarbon resistance of the various elastomers, samples were exposed to either MIL 9000 lubricating oil or 3GP11 diesel fuel. Circular samples of approximately 12 mm in diameter and 2-4 mm thickness were immersed in these liquids at room temperature for 31 days, and their masses were monitored periodically. Three replicate samples of four elastomers were exposed: Elastomer B, Elastomer C, Elastomer D, and Elastomer F.

3.3 Dynamic Mechanical Thermal Analysis

Modulus and loss factor data for the different elastomers were needed as input to VAST finite element models of engine mounts, or VVES models of engine isolation systems. For each viscoelastic material these codes require the complex Young's modulus and Poisson's ratio as a function of frequency. Alternatively, the complex shear and bulk moduli may be used as input.

For each of the elastomers, dynamic mechanical thermal analysis (DMTA) was carried out using a TA Instruments DMTA 2980 with tension clamps at 20^{o}C and over the frequency range 0.1 Hz to 200 Hz. In some cases additional types of DMTA experiments were carried out, including quasi-static stress-strain, dynamic strain amplitude sweep, and dynamic modulus versus temperature.

3.4 Density

While density was a required material property input for both the VAST and VVES models, the value used in the VVES calculations did not affect the results significantly. In one example VVES calculation, changing the density from 10 kg/m^3 to 1200 kg/m^3 resulted in ~1 % change in the calculated eigenfrequencies. Densities were determined for the same elastomers that were subjected to immersion tests, i.e. Elastomer B, Elastomer C, Elastomer D, and Elastomer F, and are summarized in Table 2.

Density was determined by cutting elastomer samples into either rectangular or disk shaped pieces. Density was determined from the measured mass and calculated volume of several samples. Volume was calculated from the measured dimensions of each sample.

4. Mechanical Properties

The dynamic mechanical properties of each elastomer may be expressed in terms of the complex Young's modulus E^*

$$E^* = E' + iE'' \qquad (1)$$

where E' is the storage modulus and E'' is the loss modulus. The mechanical properties of carbon black filled rubbers are complicated by the fact that the modulus is a function of temperature T, frequency ω, stretch $\lambda = L/L_o$, and dynamic displacement ΔL:

$$E^* = E^*\left(T, \omega, \lambda, \Delta L\right) \qquad (2)$$

In a dynamic tensile experiment, the sample is always kept in tension by applying a static force F greater than the dynamic force ΔF:

$$\begin{aligned} &F > \Delta F \\ &\therefore L > L_o + \Delta L \end{aligned} \qquad (3)$$

where L_o is the initial sample length, L is the length after application of static pre-strain, and ΔL is the dynamic displacement. The DMA2980 instrument software calculates the storage modulus E' in terms of the engineering stress σ and strain γ:

$$\begin{aligned} &\sigma = \Delta F / A_o \\ &\gamma = \Delta L / L \\ &E' = \frac{\sigma}{\gamma}\cos\varphi = \frac{\Delta F}{A_o}\frac{L}{\Delta L}\cos\varphi \end{aligned} \qquad (4)$$

In the above equations, ΔF and ΔL are the dynamic force and displacements, A_o is the cross sectional area measured of the sample with no load applied, and φ is the phase angle between force and displacement. It is implicit in Equation (4) that cross sectional area is constant during the experiment. However, this is not always a realistic assumption when the tension clamps are used, since the sample dimensions can change considerably during the experiment. This occurs when the static pre-strain is altered to maintain the condition that static force must be kept greater than dynamic force.

For soft elastomeric materials, a more realistic equation can be derived which does not assume that cross sectional area is constant. Rubbers have a Poisson's ratio $\nu \sim 0.5$, i.e. their sample volume does not change significantly when deformed in tension. If we denote L_o, A_o, V_o as the initial length, cross sectional area, and volume of the sample; and L, A, V as the length, area, and volume of a deformed sample, then

$$\begin{aligned} &V_o = V = L_o A_o = LA \\ &\therefore A = \frac{V_o}{L} \end{aligned} \qquad (5)$$

If we define the dynamic stress in terms of the pre-strained cross sectional area A, $\sigma = \Delta F / A$, then the storage modulus is given by

$$E' = \frac{\Delta F}{A}\frac{L}{\Delta L}\cos\varphi = \frac{\Delta F}{\Delta L}\frac{L^2}{V_o}\cos\varphi \qquad (6)$$

Equation (6) was used to compute "corrected" complex moduli from measured values of L, ΔF, ΔL, V_o, and φ.

4.1 Elastomer A

The dynamic mechanical properties of Elastomer A (natural rubber) are shown in Figures 4-7. The temperature dependence of the storage modulus and loss factor is shown in Figure 4 and Figure 5. The glass transition temperature is approximately –50°C (taken as the peak of the loss factor curve Figure 5). The complex modulus of this material over the frequency range 1-300 Hz was required for modelling the reduced scale experiments carried out at PSL. The procedure used to estimate the properties over this frequency range was as follows:

a) The frequency dependent complex modulus was measured at 20°C at the following frequencies: 0.1, 0.2, 0.5, 1, 2, 5, 50, and 100 Hz. The 100 Hz data was discarded as this was in the region of a machine/ sample resonance.
b) A spline function* was used to interpolate/ extrapolate the storage modulus and loss factor data over a logarithmic frequency range $\log f$ = [-1:0.1:3] Hz, or $f = 10^{-1}$ to 10^3 Hz in increments of $10^{0.1}$ Hz.
c) A second interpolation† was carried out with data from (b) over a linear frequency range f = [1:1:300] Hz.

The results of this fitting procedure are shown in Figure 6 for storage modulus and Figure 7 for loss factor. Note that the dynamic displacement amplitudes in the room temperature range were ~45 µm for this material. As was discovered later, a larger dynamic amplitude of ~400 µm was found to give more consistent results‡, and was used in the characterization of Elastomers B through F. However, as discussed in Reference 1, the VVES modelling of small scale systems using the dynamic mechanical data presented in Figure 6 and Figure 7 for Elastomer A resulted in excellent agreement with experimental data (<10% difference between experimental results and model predictions).

Note that the loss factors for natural rubber are very low, tan δ < 0.06 in the room temperature range.

* The Matlab function PCHIP (Piecewise Cubic Hermite Interpolating Polynomial) was used in the interpolation. See http://www.mathworks.com/access/helpdesk/help/techdoc/ref/pchip.html
† The Matlab function INTERP1 was used, with linear interpolation method. See http://www.mathworks.com/access/helpdesk/help/techdoc/ref/interp1.html
‡ Consistency between dynamic shear modulus and dynamic tensile modulus data was achieved at higher displacement amplitudes, using the correction procedure of Equation (6).

4.2 Elastomer B

Figure 8 shows the quasi-static stress-strain curve for Elastomer B (blend of nitrile rubber, PVC, and DIOP) up to 110% strain. This material is clearly non-linear in nature over the strain range investigated, i.e. the tangent to the stress-strain curve depends on the strain, $E = E(\gamma) = \partial\sigma/\partial\gamma$. The stress-strain curves were determined for Elastomers B, C, D, and E in order that the effect of pre-load on engine mount properties could be determined numerically using non-linear finite element analysis for the engine mounts associated with the CPF PDE and NETE MWM engines. This capability exits in VAST, but requires hyperelastic material properties such as those presented in Figure 8. Non-linear VAST FE analyses have been carried out on the PDE engine mount, the PDE raft mount, and the NETE mount, as discussed in detail in Reference 9 [contractor reports].

Elastomer B has a higher glass transition temperature (T_g) than Elastomer A. From the 1 Hz loss factor maximum in Figure 10, $T_g \sim -10^oC$.

Figure 11 shows the effect of dynamic strain amplitude on the storage modulus for Elastomer B. Note that when the data is corrected for changes in cross-sectional area (Figure 11b), the modulus remains relatively constant in the amplitude range 400 – 600 μm. The frequency dependence of the room temperature storage modulus and loss factor are shown in Figure 12 and Figure 13, respectively. This data was used in VAST and VVES models of the PDE engine isolation system, to examine the effect of changing elastomers on the isolation performance [1].

4.3 Elastomer C

The mechanical properties of Elastomer C (ethylene acrylic elastomer) are shown in Figures 14-19. As in the case of Elastomer B, the frequency dependent storage moduli and loss factors (Figure 18 and Figure 19) were used in VAST and VVES models of the PDE engine isolation system [1]. Compared with Elastomer B, it has a lower T_g, and higher loss factor at room temperature.

4.4 Elastomer D

Elastomer D is a carbon black filled natural rubber used in the PDE engine mounts. The stress-strain curve, and dynamic properties as a function of amplitude and frequency are shown in Figures 20-23. Compared with Elastomer A and Elastomer D, which are also carbon black filled natural rubbers, it has a similar room temperature modulus (3.5 MPa) but much higher loss factor (~0.2).

4.5 Elastomer E

Elastomer E is a carbon black filled natural rubber used in the PDE raft mounts. The stress-strain curve, and dynamic properties as a function of amplitude and frequency are shown in Figures 24-27. The room temperature modulus is nearly flat with frequency at ~3 MPa, and the loss factor is very low, ~ 0.1. The dynamic mechanical properties of Elastomer E (raft mount elastomer) and Elastomer D (engine mount elastomer) were used in VAST and VVES models of the PDE engine isolation system [1].

4.6 Elastomer F

Elastomer F is a carbon black filled neoprene rubber used in the manufacture of the NETE engine mounts. The tensile dynamic mechanical properties of this elastomer from are presented in Figures 28-30. It has a room temperature modulus of ~4 MPa and a loss factor of ~0.1. The dynamic mechanical properties of Elastomer F were used in VAST and VVES models of the NETE engine isolation system [1,9].

4.7 Poisson's Ratio

The Poisson's ratio was not measured directly, but estimated from modulus data. Most soft elastomers have a Poisson's ratio ν ~ 0.5, and this value decreases as the modulus increases with increasing frequency or decreasing temperature. In a review of the literature carried out at DRDC Atlantic [10], it was shown that for a number of polymers in the rubbery state, the complex Poisson's ratio ν* may be estimated from the complex Young's modulus E* using the relationship

$$\nu^* = 0.5 - \left(7.74 \cdot 10^{-11}\right) E^* \qquad (7)$$

Note that the following relationship between Poisson's ratio, bulk modulus K, and Young's modulus [11] is consistent with Equation (7):

$$\nu = \frac{1}{2} - \frac{E}{6K} \qquad (8)$$

The two equations above imply that the dynamic bulk modulus is similar for most elastomers, and that it changes very slowly with temperature and frequency. From (7) and (8), K may be estimated by

$$K \sim 1 \big/ \left(6 * 7.74 \cdot 10^{-11}\right) \sim 2.15 \cdot 10^{9}\,\mathrm{Pa} \qquad (9)$$

This value is comparable to the mean value of K ~ 3 GPa that Burns *et al* found from an experimental investigation of the dynamic bulk properties of a variety of elastomers [12].

For the purposes of finite element modelling using VAST and vibration isolation modelling using VVES, Equation (7) was used to estimate the frequency dependent complex Poisson's ratio, using experimentally derived values of *E*(ω)* presented in Section 9.

5. Hydrocarbon Compatibility

When a crosslinked elastomer is in contact with a hydrocarbon fluid such as diesel fuel or lubricating oil, the hydrocarbon molecules diffuse into the polymer network, causing it to increase in mass and volume (swell). The swelled network will generally have a lower modulus, lower strength, and lower glass transition temperature than the non-swelled elastomer. The increase in mass upon exposure to diesel fuel or lubricating oil provides a general indication of an elastomer's compatibility with that fluid. However, it should be pointed out that low molecular weight fractions in the elastomer can diffuse out of the polymer into the fluid, lessening the overall mass increase. One must be especially careful in interpreting fluid uptake data for the case of a heavily plasticized elastomer, such as Elastomer B.

Figure 31 presents the mass increase of four elastomers immersed in 3GP11 diesel fuel over a 31 day period. Natural rubber (Elastomer A) and neoprene rubber (Elastomer F) experienced greater than 100% mass increases, whereas the more hydrocarbon resistant Elastomers B and C had mass increases of 5% and 37%, respectively. In MIL 9000 lubricating oil there was less fluid uptake than that caused by diesel fuel for all four elastomers, as shown in Figure 32. Natural rubber and neoprene had mass increases of 22% and 39%, respectively, in MIL 9000 oil. The NBR/ PVC/ DIOP blend (Elastomer B) experienced a mass *loss* of 2%, and the ethylene acrylic elastomer (Elastomer C) experienced a mass increase 2% in MIL 90000. The mass loss for Elastomer B most likely reflects both diffusion of plasticizer out of the elastomer, as well as oil diffusion into the elastomer.

Based on the mass uptake results, ethylene acrylic elastomer (Elastomer C) would be a suitable replacement for natural rubber and neoprene rubber in engine mounts where exposure to hydrocarbon fluids is a concern. The data for NBR/ PVC/ DIOP blend (Elastomer B) suggest that some plasticizer leaching occurs on exposure to lubricating oil, and therefore this elastomer cannot be recommended without further examination of this issue.

6. Summary and Conclusions

The dynamic mechanical properties of the elastomers were determined as a function of frequency and strain amplitude. At strain amplitudes > 400 μm, the storage moduli were generally independent of amplitude, once the moduli were corrected for changes in sample cross-sectional area resulting from tensile pre-strain. The dynamic mechanical properties of the elastomers at 1 Hz and 20^{o}C are summarized in Table 3. The storage moduli were in the range 3-7 MPa. The loss factors of the elastomers at 1 Hz and 20^{o}C varied considerably, from 0.02 for natural rubber to 0.27 for ethylene acrylic elastomer.

Swelling experiments of the elastomers in diesel fuel and lubricating oil demonstrated that the two elastomers prepared by PSL were in fact quite resistant to hydrocarbons. However, the hydrocarbon compatibility data for nitrile rubber/ plasticized PVC blend suggest that some plasticizer leaching occurred on exposure to lubricating oil.

The frequency-dependent dynamic mechanical properties of the elastomers presented in this report were used in VAST Finite Element models of engine mounts, and in VVES models of engine vibration isolation systems. Hydrocarbon compatibility experiments suggest that ethylene acrylic elastomer would be a suitable replacement for natural rubber and neoprene rubber in engine mounts where exposure to hydrocarbon fluids is a concern.

7. References

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8. Tables

Table 1. List of elastomers studied.

DESIGNATION	TYPE OF ELASTOMER	DESCRIPTION
A	Natural Rubber	Formulated at PSL. Used in small scale tests at PSL.
B	Blend of nitrile rubber, PVC, and DIOP	Formulated at PSL as AMRL 2046.
C	Ethylene acrylic elastomer	Formulated at PSL as AMRL 2047.
D	Natural rubber	PDE engine mount elastomer
E	Natural rubber	PDE raft mount elastomer
F	Neoprene rubber	Lord mount used with NETE MWM engine

Table 2. Densities of the elastomers.

		DENSITY (kg/m^3)	
	TYPE OF ELASTOMER	AVERAGE	STANDARD DEVIATION
B	Blend of nitrile rubber, PVC, and DIOP	1314	18
C	Ethylene acrylic elastomer	1262	33
D	Natural rubber	1162	33
F	Neoprene rubber	1201	38

Table 3. Summary of dynamic mechanical properties at 20°C and 1 Hz.

DESIGNATION	TYPE OF ELASTOMER	STORAGE MODULUS (MPa)	LOSS FACTOR
A	Natural Rubber	3.4	0.03
B	Blend of nitrile rubber, PVC, and DIOP	6.6	0.22
C	Ethylene acrylic elastomer	5.4	0.27
D	Natural rubber	3.4	0.19
E	Natural rubber	3.0	0.02
F	Neoprene rubber	4.8	0.11

9. Figures

Figure 1. Metalastik® type D series, Product No. 17-1601-03

Figure 2.Lord Corporation Flexbolt Sandwich Mount, Part number J-5130-1.

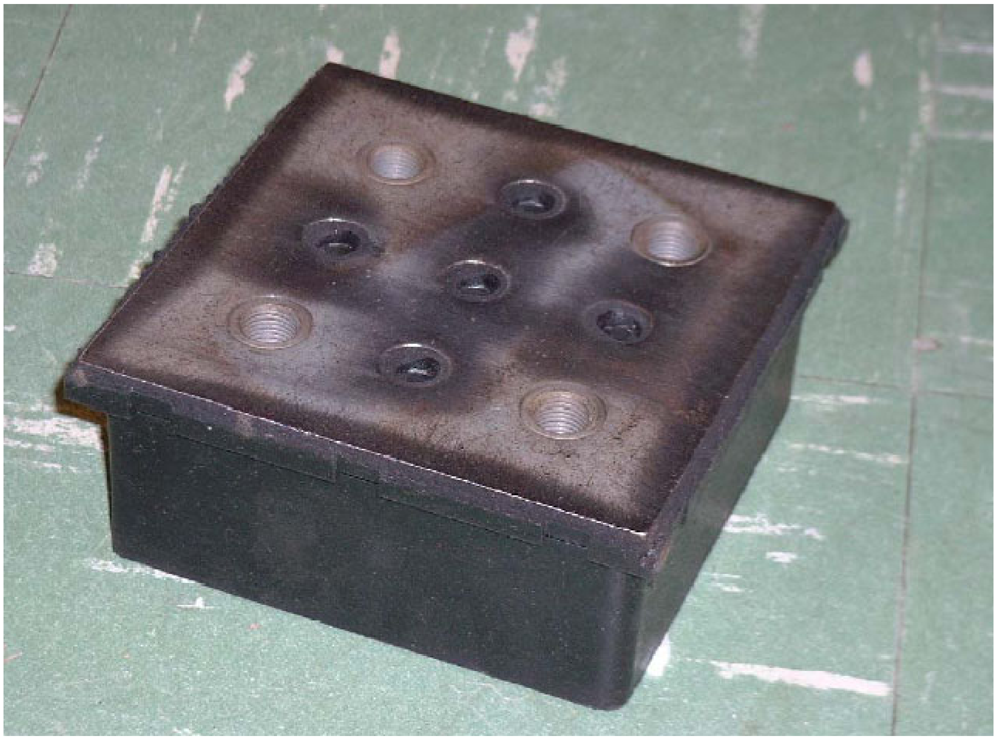

Figure 3. Lord Corporation Flexbolt Sandwich Mount, Part number J-5130-1

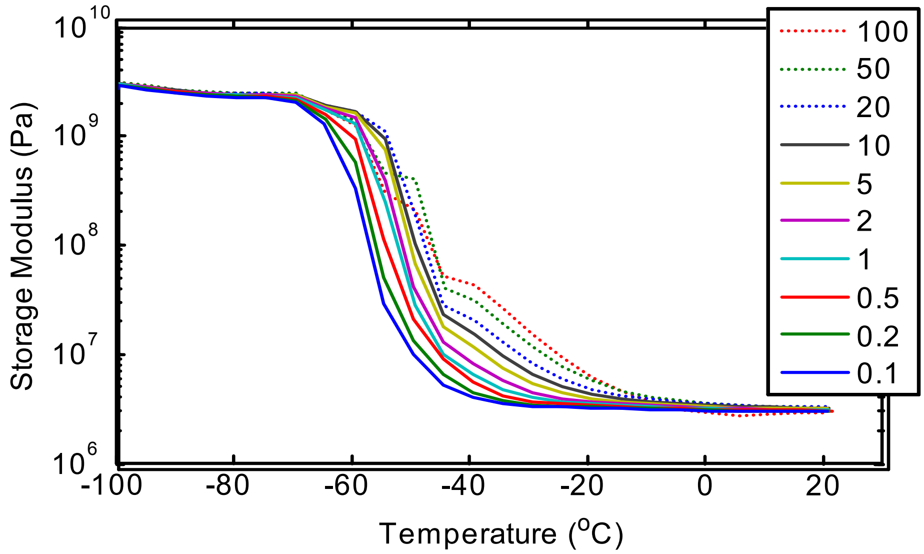

Figure 4. Storage modulus versus temperature for Elastomer A. Legend entries correspond to frequencies ranging from 0.1 Hz to 100 Hz.

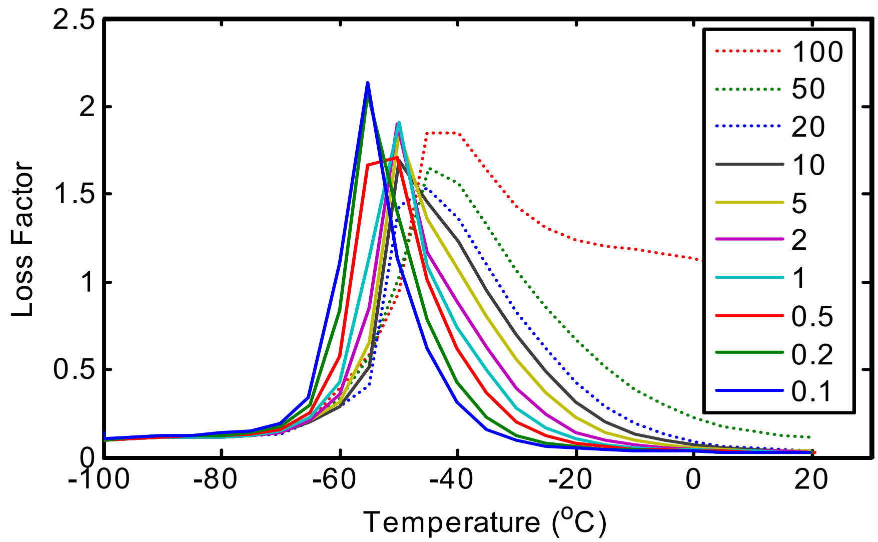

Figure 5. Loss factor versus temperature for Elastomer A. Legend entries correspond to frequencies ranging from 0.1 Hz to 100 Hz..

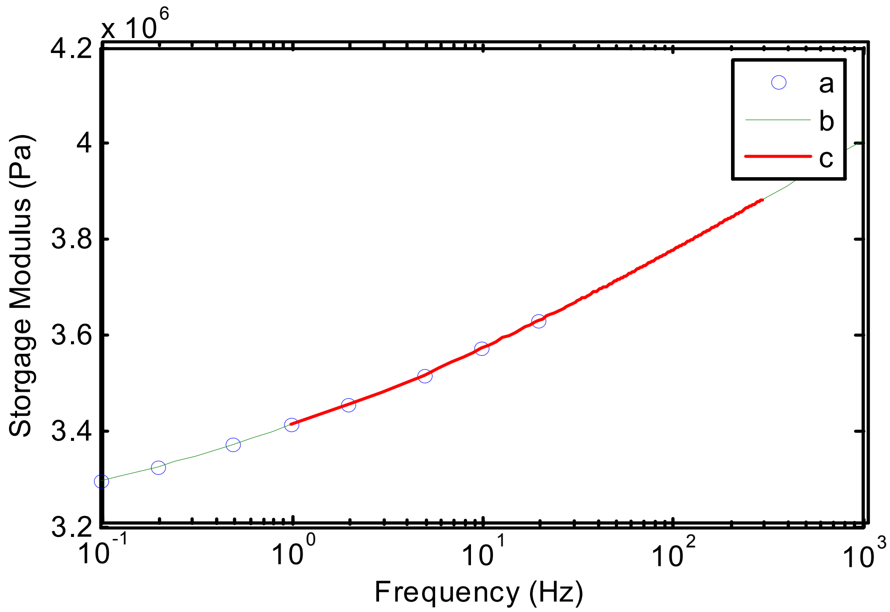

Figure 6. Storage modulus versus frequency at 20°C for Elastomer A. (a) Experimental data, (b) logarithmic interpolation/ extrapolation between 10^{-1} and 10^{3} Hz. (c) linear interpolation of data from (b) from 1 to 300 Hz.

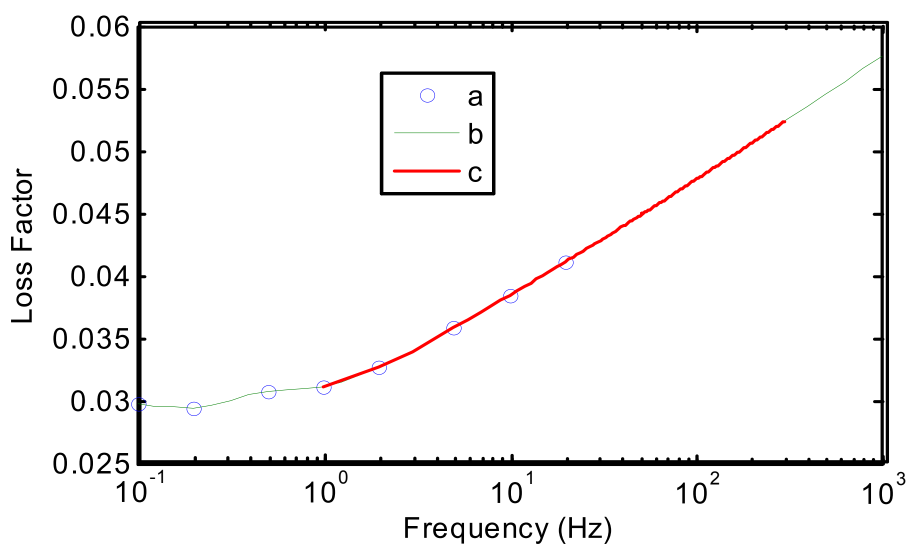

Figure 7. Loss factor versus frequency at 20°C for Elastomer A. (a) Experimental data, (b) logarithmic interpolation/ extrapolation between 10^{-1} and 10^{3} Hz. (c) linear interpolation of data from (b) from 1 to 300 Hz.

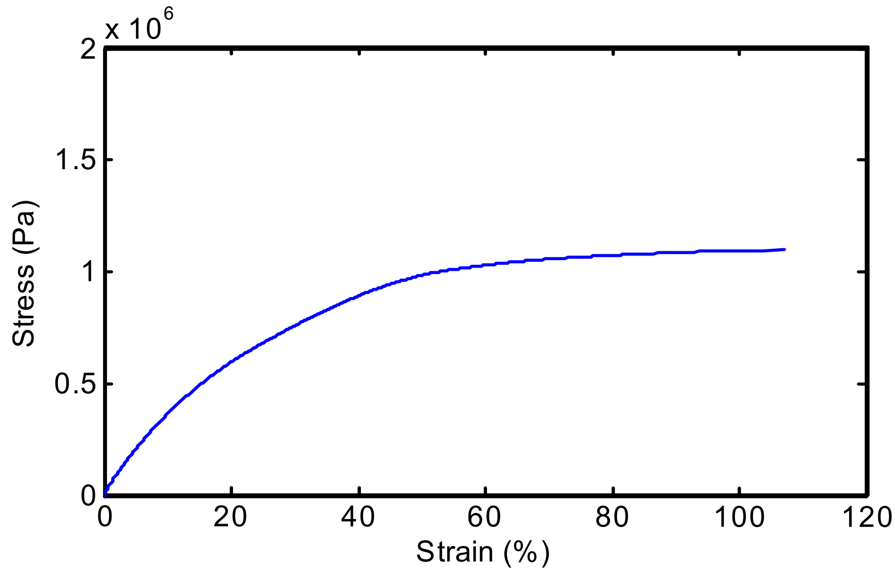

Figure 8. Quasi-static stress-strain curve for Elastomer B at 20°C. Force was ramped at 0.5 N/min.

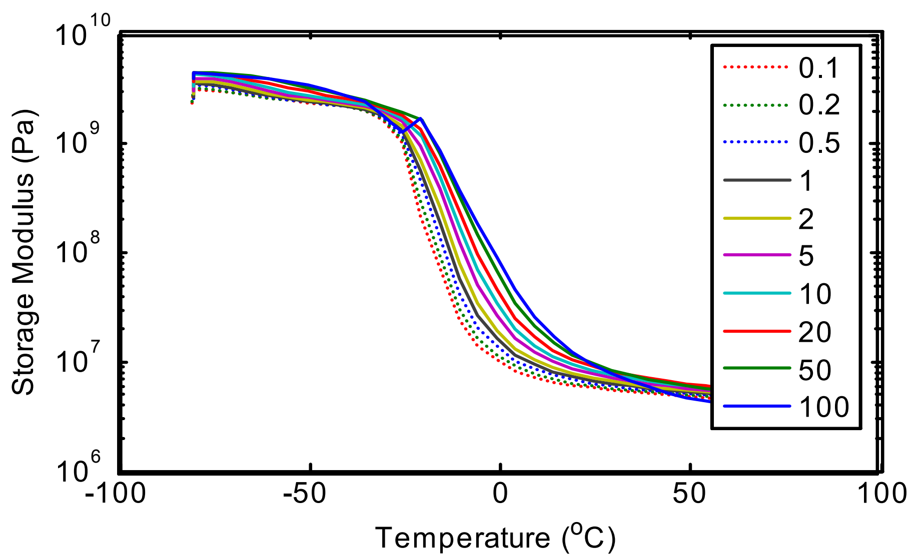

Figure 9. Storage modulus versus temperature for Elastomer B. Legend entries correspond to frequencies ranging from 0.1 Hz to 100 Hz..

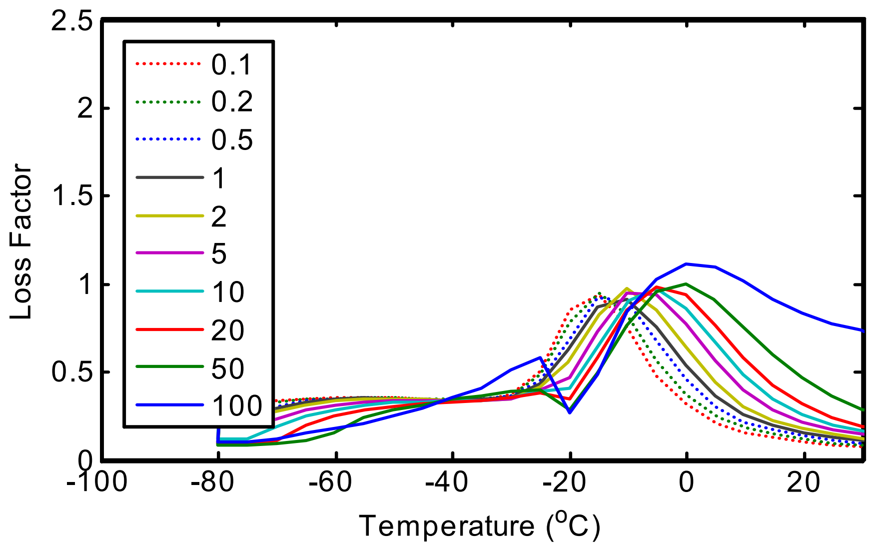

Figure 10. Loss factor versus temperature for Elastomer B. Legend entries correspond to frequencies ranging from 0.1 Hz to 100 Hz..

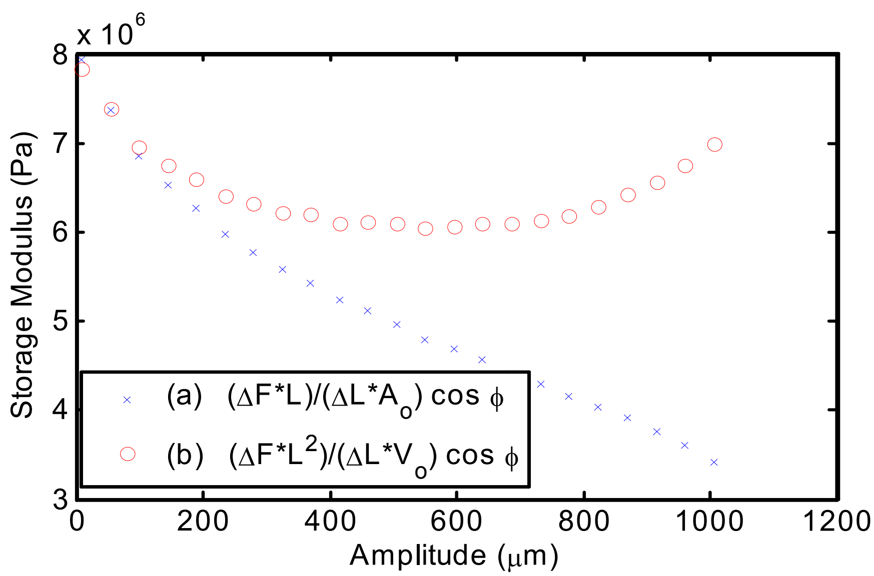

Figure 11. Storage modulus versus dynamic strain amplitude for Elastomer B at 1 Hz and 20°C. (x) Calculated from engineering stress and strain, (o) calculated using Equation (6).

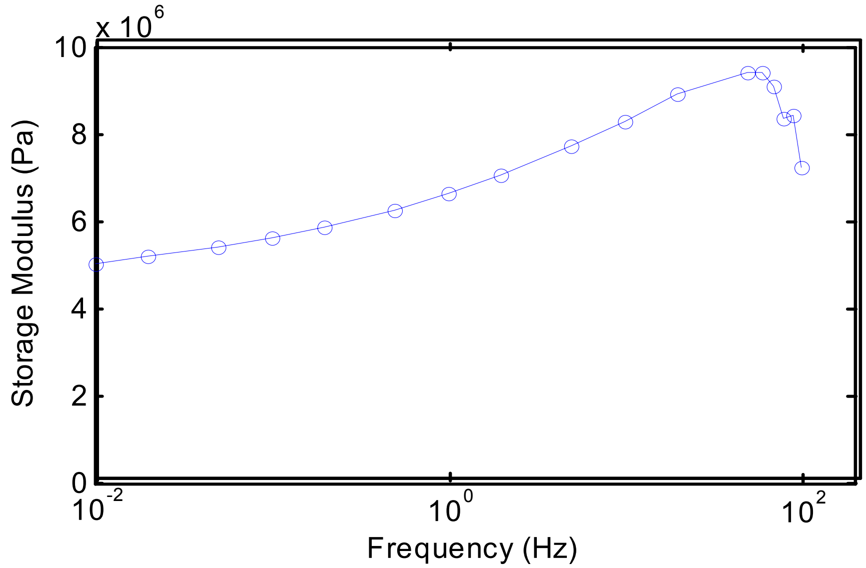

Figure 12. Storage modulus as a function of excitation frequency for Elastomer B at 20°C and 400 μm dynamic strain amplitude.

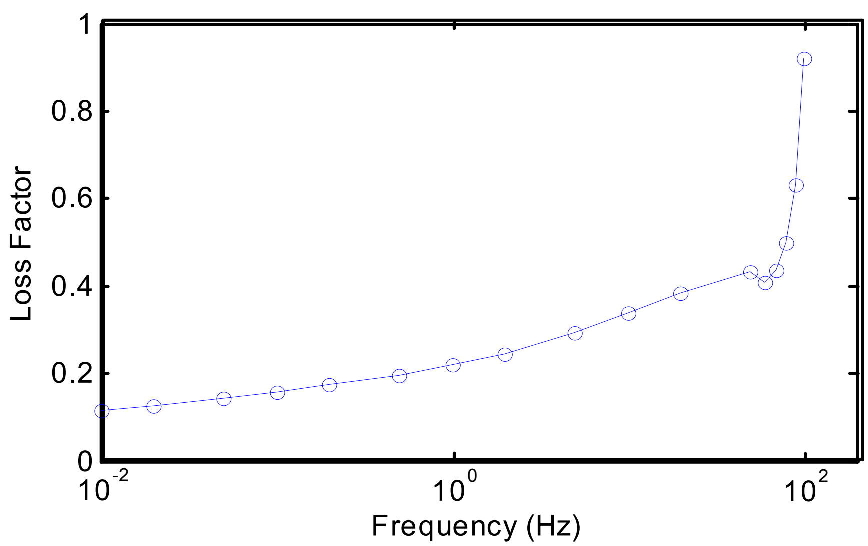

Figure 13. Loss factor as a function of excitation frequency for Elastomer B at 20°C and 400 μm dynamic strain amplitude.

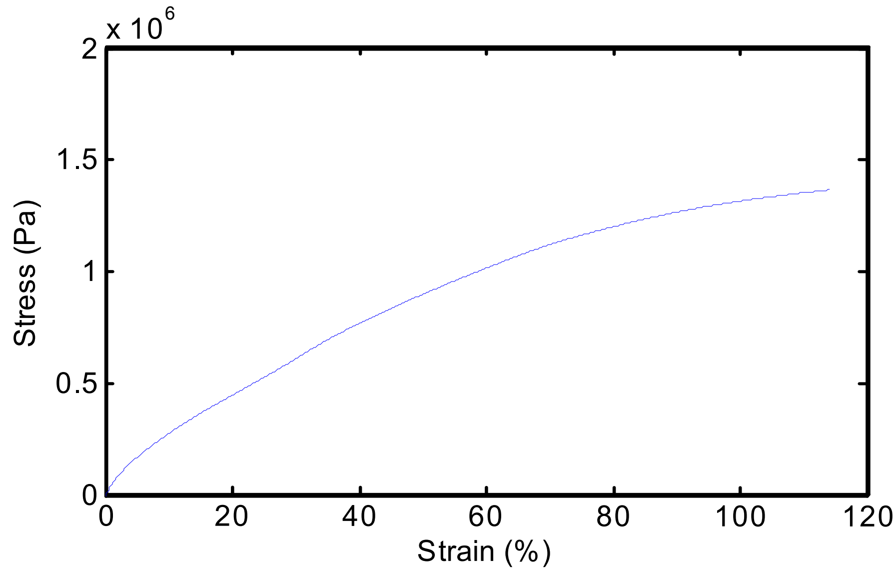

Figure 14. Quasi-static stress-strain curve for Elastomer C at 20°C. Force was ramped at 0.5 N/min.

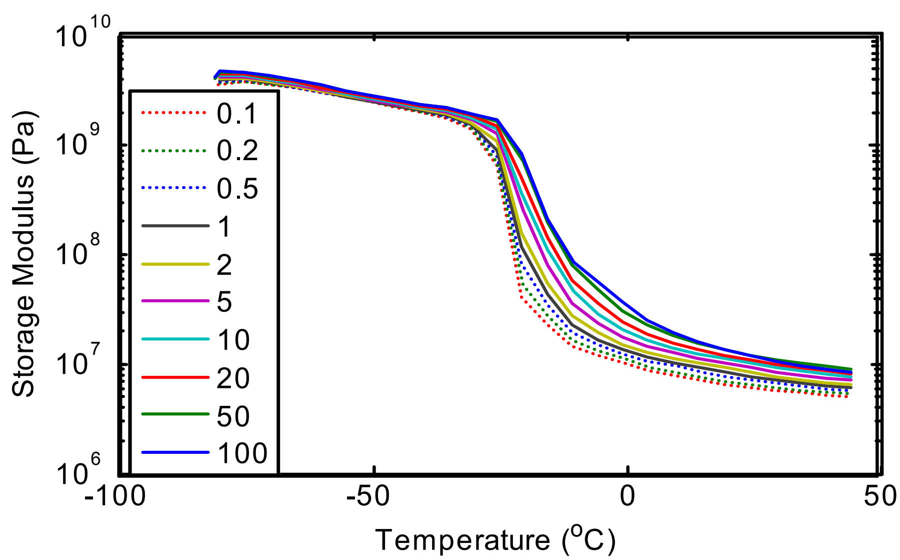

Figure 15. Storage modulus versus temperature for Elastomer C. Legend entries correspond to frequencies ranging from 0.1 Hz to 100 Hz.

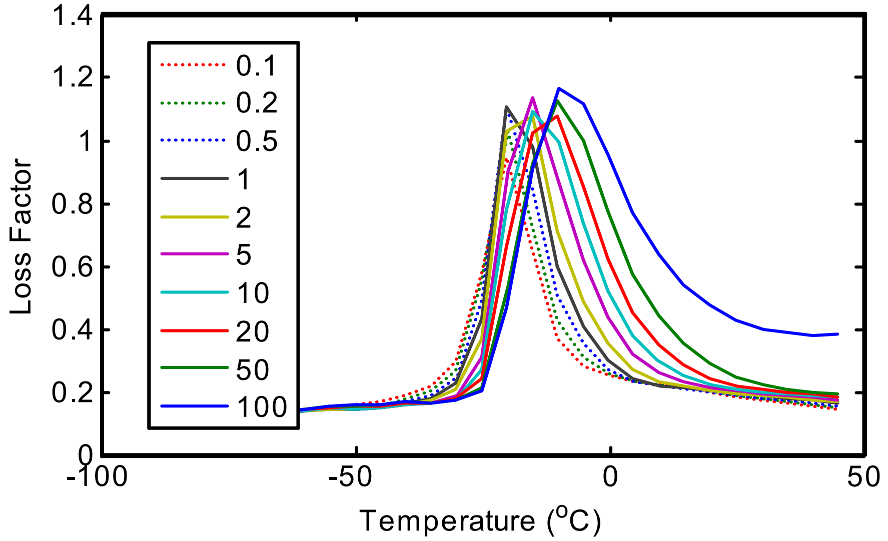

Figure 16. Loss factor versus temperature for Elastomer C. Legend entries correspond to frequencies ranging from 0.1 Hz to 100 Hz.

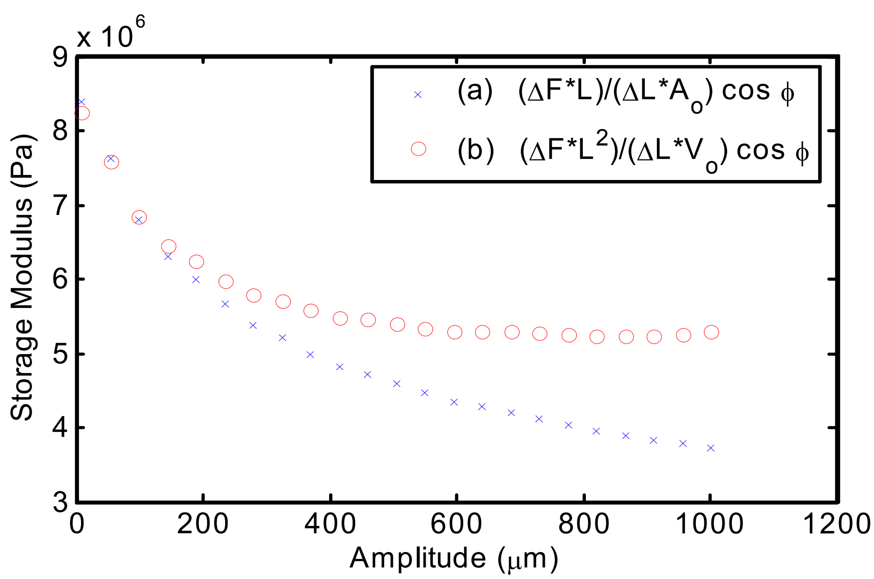

Figure 17. Storage modulus versus dynamic strain amplitude for Elastomer C at 1 Hz and 20°C. (x) Calculated from engineering stress and strain, (o) calculated using Equation (6).

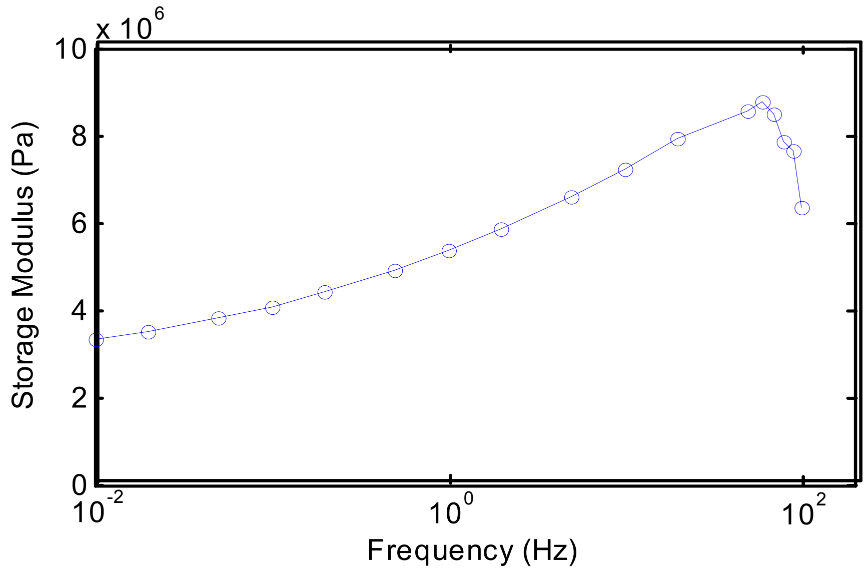

Figure 18. Storage modulus as a function of excitation frequency for Elastomer C at 20°C and 400 μm dynamic strain amplitude.

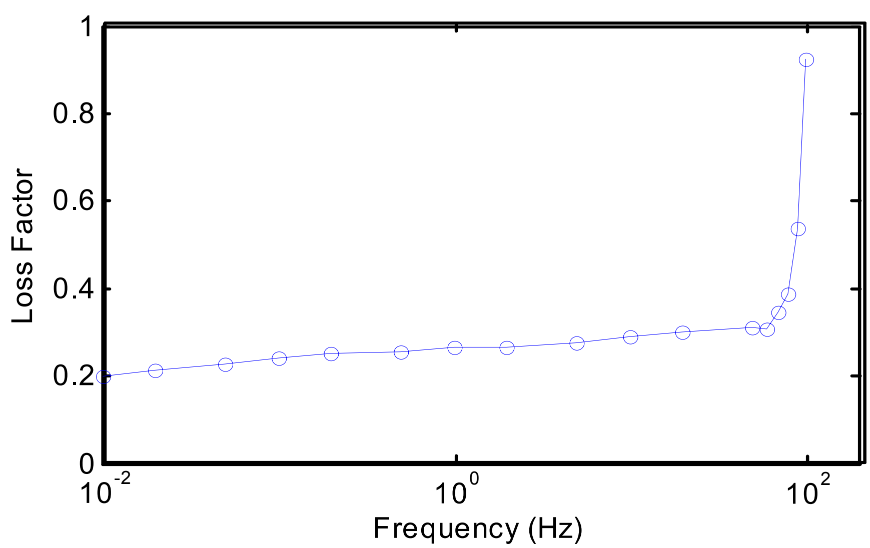

Figure 19. Loss factor as a function of excitation frequency for Elastomer C at 20°C and 400 μm dynamic strain amplitude.

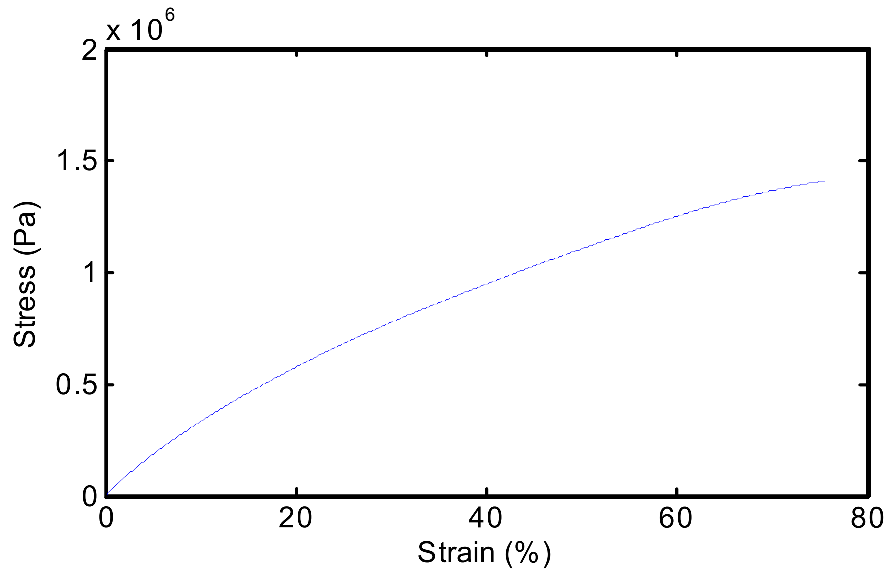

Figure 20. Quasi-static stress-strain curve for Elastomer D at 20°C. Force was ramped at 0.5 N/min.

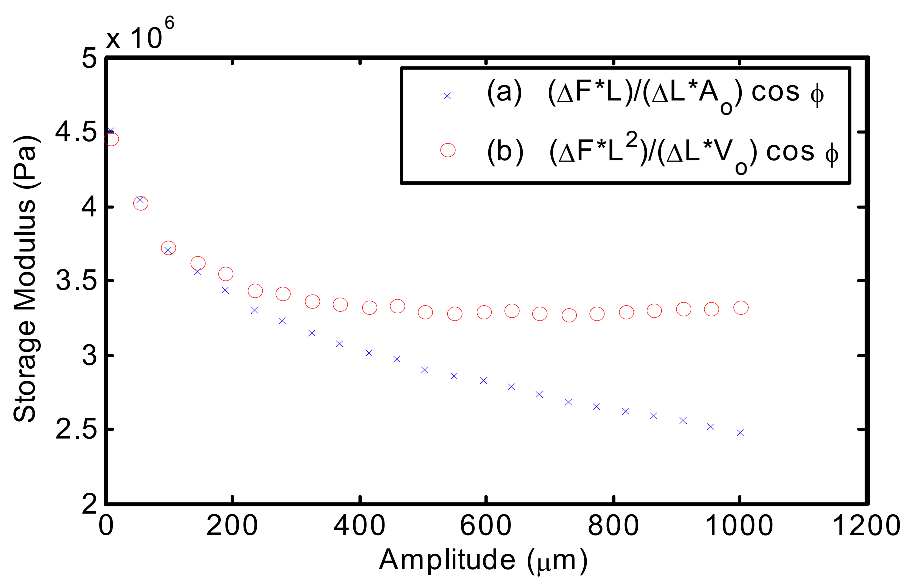

Figure 21. Storage modulus versus dynamic strain amplitude for Elastomer D at 1 Hz and 20°C. (x) Calculated from engineering stress and strain, (o) calculated using Equation (6).

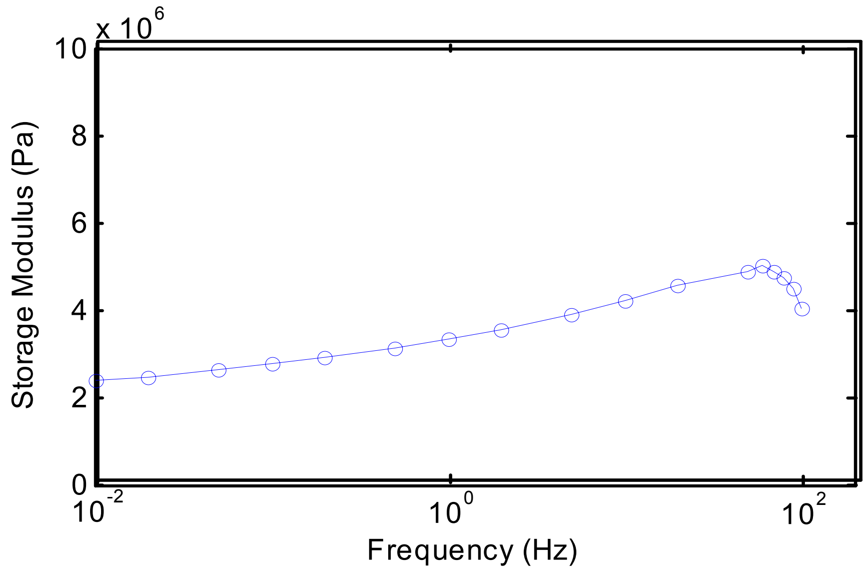

Figure 22. Storage modulus as a function of excitation frequency for Elastomer D at 20°C and 400 μm dynamic strain amplitude.

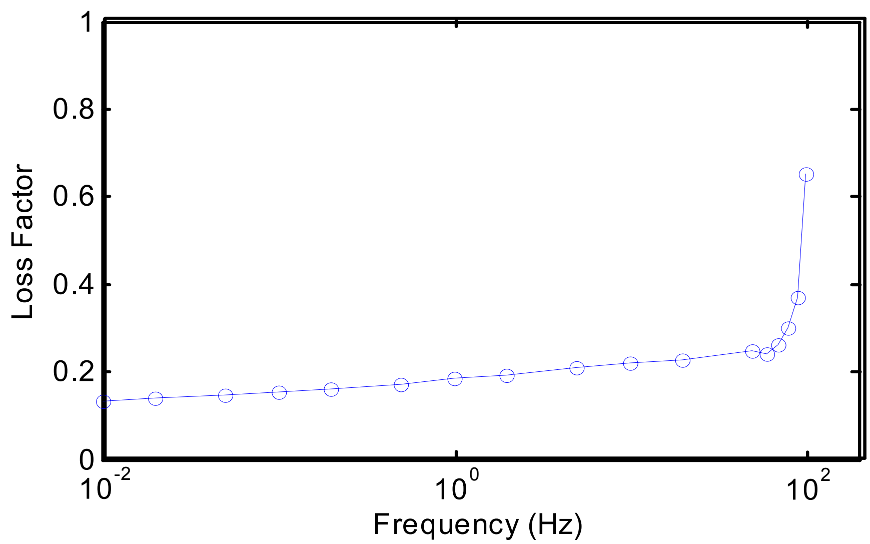

Figure 23. Loss factor as a function of excitation frequency for Elastomer D at 20°C and 400 μm dynamic strain amplitude.

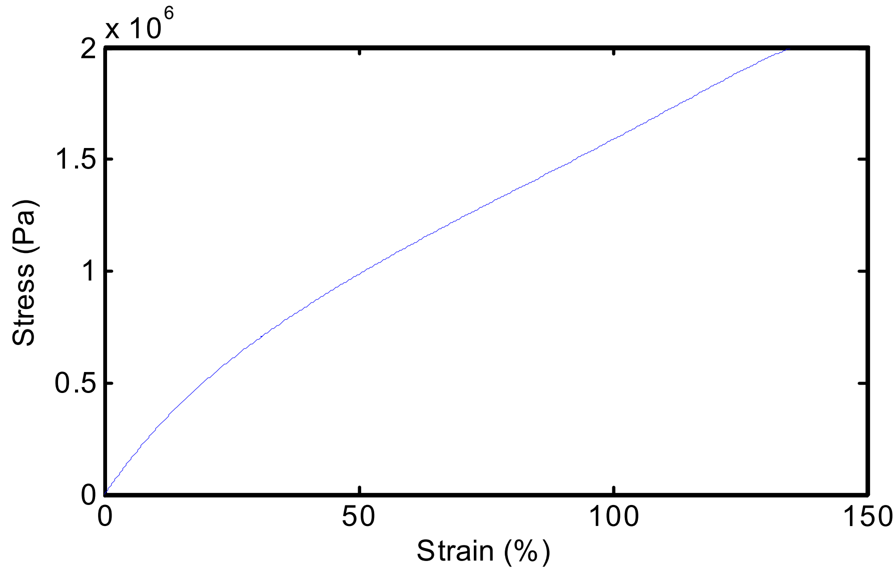

Figure 24. Quasi-static stress-strain curve for Elastomer E at 20°C. Force was ramped at 0.5 N/min.

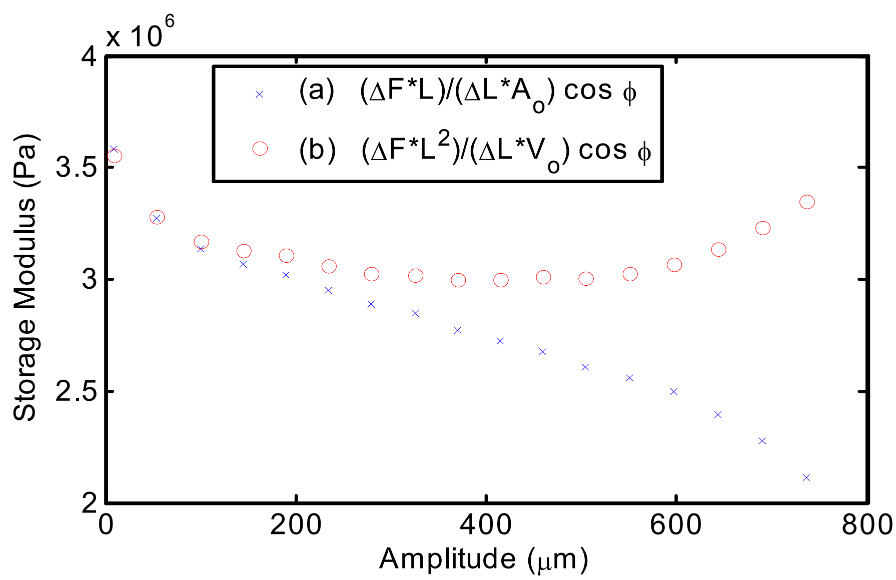

Figure 25. Storage modulus versus dynamic strain amplitude for Elastomer E at 1 Hz and 20°C. (x) Calculated from engineering stress and strain, (o) calculated using Equation (6).

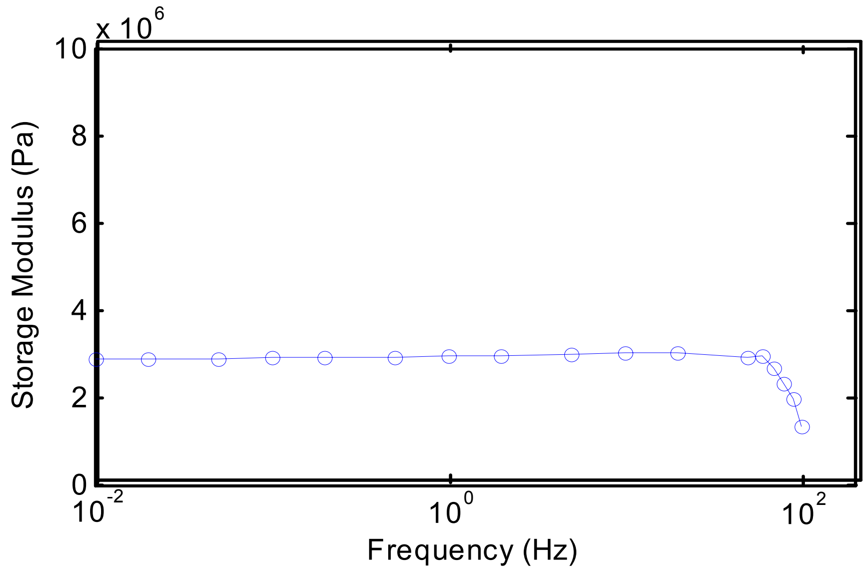

Figure 26. . Storage modulus as a function of excitation frequency for Elastomer E at 20°C and 400 μm dynamic strain amplitude.

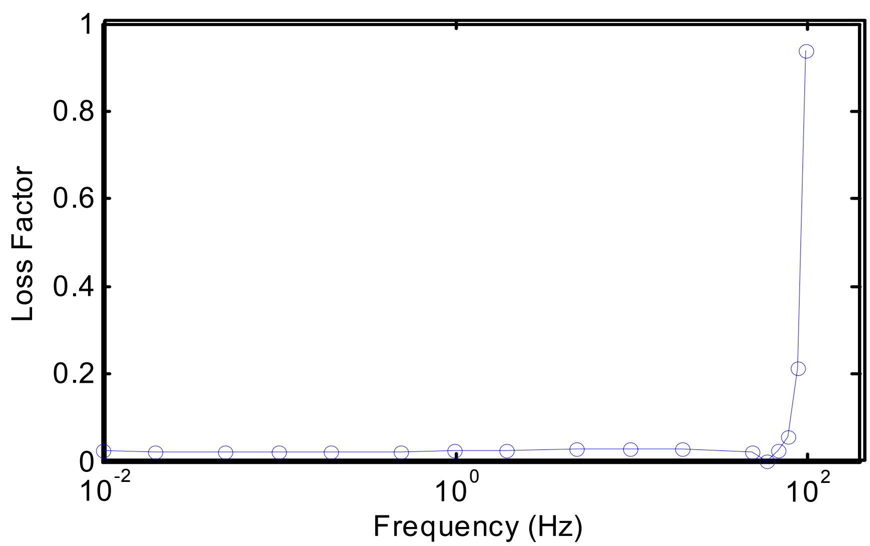

Figure 27. Loss factor as a function of excitation frequency for Elastomer E at 20°C and 400 μm dynamic strain amplitude.

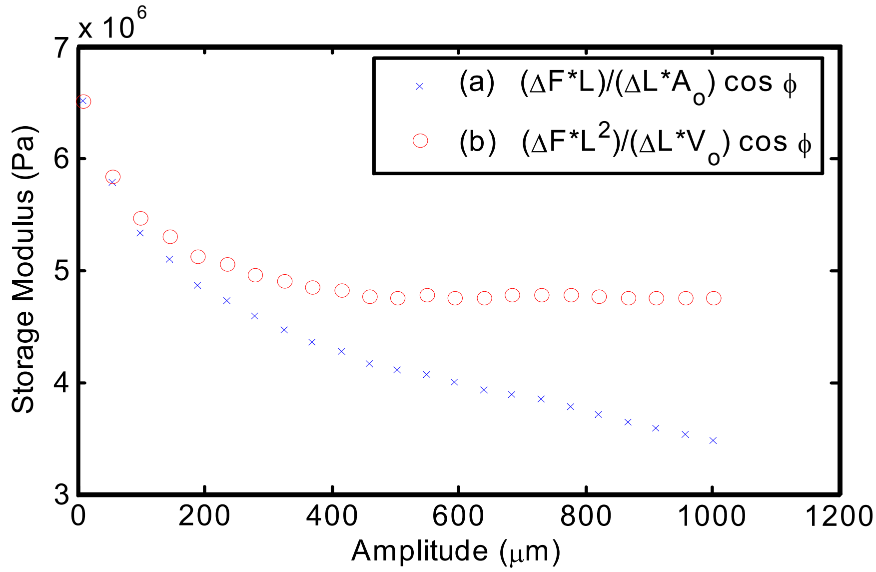

Figure 28. Storage modulus versus dynamic strain amplitude for Elastomer F at 1 Hz and 20°C. (x) Calculated from engineering stress and strain, (o) calculated using Equation (6).

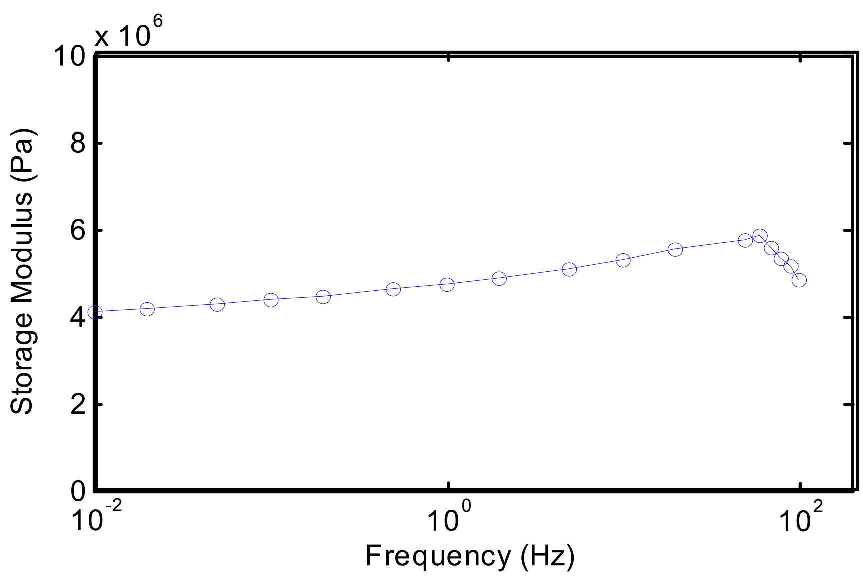

Figure 29. Storage modulus as a function of excitation frequency for Elastomer F at 20°C and 400 μm dynamic strain amplitude.

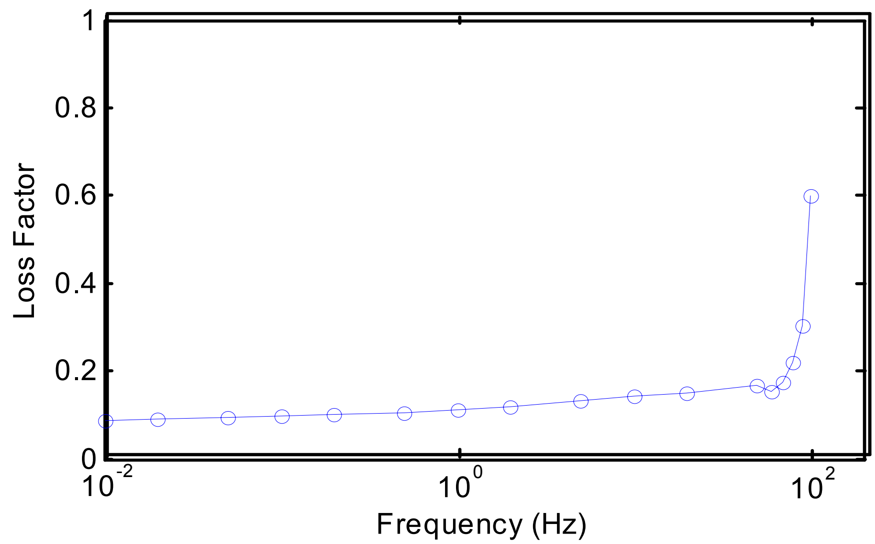

Figure 30. Loss factor as a function of excitation frequency for Elastomer F at 20°C and 400 μm dynamic strain amplitude.

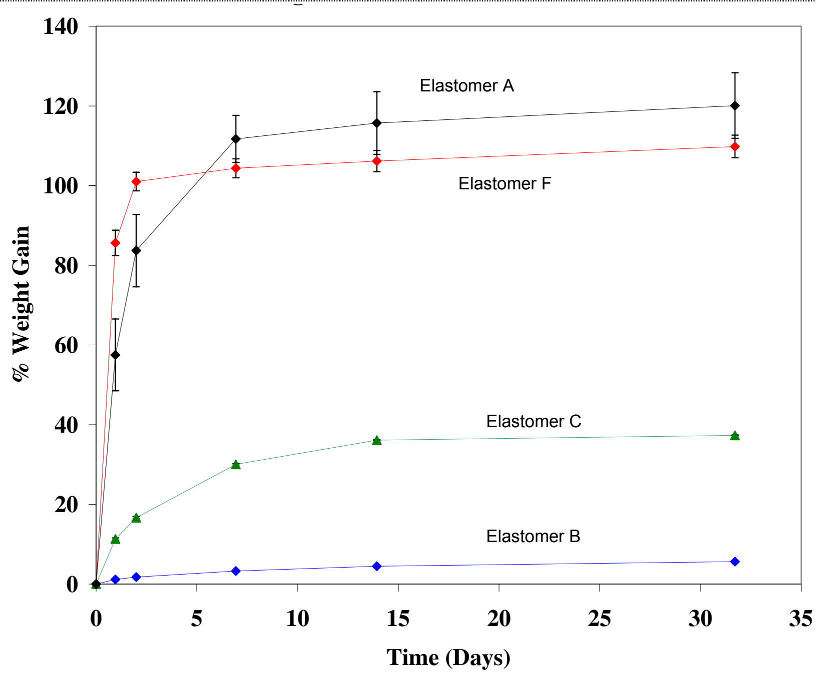

Figure 31. Weight change as a function of time for samples immersed in 3GP11 diesel fuel. Error bars represent ± one standard deviation.

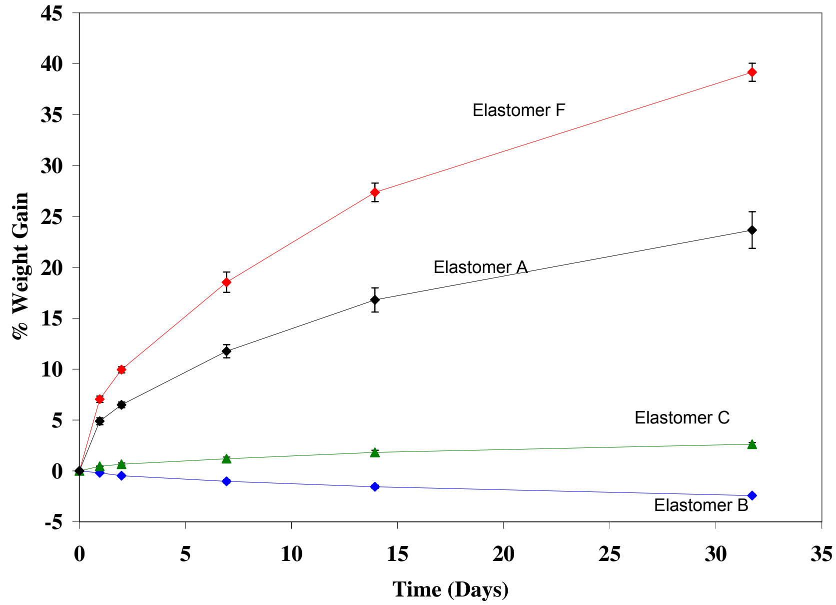

Figure 32. Weight change as a function of time for samples immersed in MIL 9000 lubricating oil. Error bars represent ± one standard deviation.

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DMSS	Director Maritime Ship Support
TA Project	Technology Applications Project
WBE	Work Breakdown Element
PSL	Platform Sciences Laboratory, formerly AMRL, Melbourne Australia
DRDC Atlantic	Defence R&D Canada – Atlantic, formerly DREA
DIOP	Diisooctyl phthalate; 1,2-Benzenedicarboxylic acid, diisooctyl ester
PDE	Propulsion Diesel Engine
CPF	Canadian Patrol Frigate
NETE	Naval Engineering Test Establishment
VAST	Vibration and Strength. Finite element code developed by DRDC and Martec
VVES	Vibration of Viscoelastic and Elastic Systems. Vibration isolation modelling code developed by Prof. Stan Hutton at UBC.
VIMGEN	Vibration Isolation Model Generator. Graphical User Interface for VVES developed by Martec

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As part of a project to develop methods for modelling the performance of engine mounts, several oil resistant alternative materials were prepared, and compared to conventional materials from mounts that are currently in service on the Canadian Patrol Frigate (CPF). This report describes the preparation and characterization of these elastomers, including two that were prepared at Platform Sciences Laboratory (PSL) in Melbourne, Australia under the Canada/ Australia MOU on Defence Science and Technology, Subsidiary Arrangement No. 16, Vibration Isolation Materials For Naval Vessels.

The dynamic mechanical properties of the elastomers were determined as a function of frequency and strain amplitude. At strain amplitudes > 400 μm, the storage moduli were generally independent of amplitude, once the moduli were corrected for changes in sample cross-sectional area resulting from tensile pre-strain. The storage moduli at 1 Hz, 20°C were in the range 3-7 MPa. The loss factors of the elastomers at 1 Hz, 20°C varied considerably, from 0.02 for natural rubber to 0.27 for ethylene acrylic elastomer. Swelling experiments of the elastomers in diesel fuel and lubricating oil demonstrated that the two elastomers prepared by PSL were in fact quite resistant to hydrocarbons. However, the hydrocarbon compatibility data for nitrile rubber/ plasticized PVC blend suggest that some plasticizer leaching occurred on exposure to lubricating oil.

The frequency-dependent dynamic mechanical properties of the elastomers presented in this report were used in VAST Finite Element models of engine mounts, and in VVES models of engine vibration isolation systems. Hydrocarbon compatibility experiments suggest that ethylene acrylic elastomer would be a suitable replacement for natural rubber and neoprene rubber in engine mounts where exposure to hydrocarbon fluids is a concern.

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